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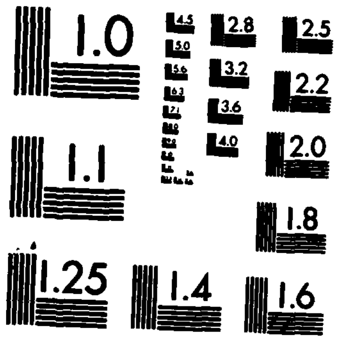

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A PARALLEL METHOD FOR NATURAL TEXTURE SYNTHESIS

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ABSTRACT

This paper deals with an optimization technique applied to natural texture synthesis. We propose a definition of a global criterion which is the mean square error between the statistical features of a natural original texture and those of an artificially generated one. A gradient algorithm is used to minimize this criterion. The statistical feature vector used was the autocorrelation function although this is by no means the only choice. The textures generated are very similar to the original ones. This method can be implemented in a highly parallel manner.

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This paper deals with an optimization technique applied to natural texture synthesis. We propose a definition of a global criterion which is the mean square error between the statistical features of a natural original textureand those of an artificially generated one. A gradient algorithm is used to minimize this criterion. The statistical feature vector used was the autocorrelation function although this is by no means the only choice. The textures generated are very similar to the original ones. This

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method can be implemented in a highly parallel manner.

1. Introduction

Texture synthesis is very important for the image reconstruction of natural scenes from compressed data. It can be applied to the generation of artificial images used in , for example, flight simulators or cinematic effects. As shown in earlier papers [1,2], second order statistics are the important features to describe the stochastical texture field with respect to the human observer. Some methods have been proposed for the synthesis of textures from their a priori given second order statistics [3,4]. The drawbacks of these methods are as follows:

1) In some of these methods, higher order statistics have to be invented which requires a memory far beyond the capabilities of any computer, especially in the case of natural texture synthesis.

2) Some other methods utilize autoregressive models which only allows control of the autocorrelation function which is often not sufficient to describe a texture . The stability of such two dimensional filters is also a very difficult problem.

In our two previous papers[5,6], we have presented a new method for natural texture synthesis. By this method, without having to invent higher order statistics, we can generate textures by controlling their second order statistics (second order spatial averages or histogram plus autocorrelation function). The results showed that the generated textures are very similar visually to the natural textures they are intended to approximate. However,this was a *sequential* method which needs a long computation time and this can be an important drawback for practical application.

In this paper, we will present a *parallel* method of texture synthesis based upon an optimization technique. Using a gradient algorithm, we minimize a global criterion which is the mean square error between the feature vector of the generated texture and that of a given reference natural texture. The parameters of the feature vector could be the second order spatial moments of the texture or any other higher order spatial moments if necessary.

2. Feature vector of a texture field

A given texture can be considered as a realization of a stochastic process. This is defined on a rectangular discrete plane and takes its value in the interval [0 , 1].

Since the discrete plane can be ordered, a point of this plane will be represented by its rank i. In what follows, a given texture will be represented by a one dimensional vector X:

$$X = (x_1 , x_2 , \ldots.. x_i , \ldots. x_N)$$

where N is the total number of points in the plane and x_i represents the value of the stochastic process at location i (or the grey level value of the texture field in the spatial position i).

We define a set of translations T_Δ :

$$T_\Delta = (\Delta_1 , \Delta_2 , \ldots. \Delta_K)$$

where each element is a displacement vector between two points , one being the center of a window,and the other one of the points of this window (see Figure 1). The autocovariance coefficients associated with each translation Δ_k are defined by

$$a_{\Delta_k} = \frac{1}{N * \sigma} \sum_{i=1}^{N} (x_i - \eta)(x_{i+\Delta_k} - \eta) \qquad \forall \Delta_k \quad T_\Delta \tag{1}$$

where η and σ are the mean and variance of the image:

$$\eta = \frac{1}{N} \sum_{i=1}^{N} x_i \tag{2}$$

$$\sigma = \frac{1}{N} \sum_{i=1}^{N} (x_i - \eta)^2 \tag{3}$$

We define a one-dimensional feature vector B composed of all the statistical parameters that we want to control in the synthesis procedure. In what follows, it will be composed of all the autocovariance parameters corresponding to the translation set T_Δ.

We will denote by B^{TX}, $a_{\Delta_k}^{TX}$, η^{TX}, σ^{TX} the feature vector,the autocovariance parameters, the mean and the variance of the generated texture, and B, a_{Δ_k}, η, σ will be the *desired* feature vec-

tor, the autocovariance parameters, the mean and the variance which are computed from the natural original texture we want to approximate. Then we have:

$$B = (a_{\Delta_1}, a_{\Delta_2}, \ldots, a_{\Delta_K})$$

$$B^{TX} = (a^{TX}_{\Delta_1}, a^{TX}_{\Delta_2}, \ldots, a^{TX}_{\Delta_K})$$

3. Synthesis procedure

A global criterion is proposed:

$$C(X) = \| B - B^{TX} \|^2 + w1(\eta - \eta^{TX})^2 + w2(\sigma - \sigma^{TX})^2 \qquad (4)$$

The first term C(X) is the mean square error of the feature vector. The second and third terms are the constraints of the mean and variance of the texture image, where w1 and w2 are very large numbers.

Our synthesis procedure is : from an initial value X^0, which is white noise having the desired mean and variance, we use an iterative algorithm (called a gradient algorithm) to minimize the global criterion C(X) defined previously. In the n^{th} iteration of the algorithm

$$X^{n+1} = X^n - \rho^n G^n$$

where G^n is the criterion's gradient at point X^n and ρ^n is a positive number.

From (1-4), we can calculate G^n :

$$G^n = (G_1^n , G_2^n , \cdots G_i^n , \cdots G_N^n)^T$$

$$G_i^n = \frac{dC(X)}{dz_i} = \frac{2}{N}\left[\sum_{\Delta_k} \frac{(s_{\Delta_k} - s_{\Delta_k}^{TX})}{\sigma} (z_{i+\Delta_k} - \eta) + w1(\eta - \eta^{TX}) + 2w2(\sigma - \sigma^{TX})(z_i - \eta)\right], i = 1 - N$$

G^n can be calculated in a *parallel* manner.

ρ^n is a positive numbe. chosen so that it minimizes C(X) with the condition that z_i (i=1,N) lies inside the inter... [0,1]. This condition gives us a largest positive value ρ_{MAX} :

$$\rho_{MAX}^n = MIN (\rho_i^n)$$

$$\rho_i^n = \begin{cases} z_i^n / G_i^n & \text{if } G_i^n > 0 \\ (z_i^n - 1)/G_i^n & \text{if } G_i^n < 0 \\ \infty & \text{if } G_i^n = 0 \end{cases}$$

For simplicity, we take $\rho^n = \rho^n_{MAX}$, although this is not optimal. Further explanation of this gradient algorithm can be found in [7].

4. Results

This parallel algorithm proposed has been simulated sequentially by computer. Four different types of textures have been synthesized (SAND, SEISMIC PICTURE, RATTAN and WOOL). SAND and SEISMIC PICTURE have been synthesized by controlling their autocovariance parameters in a 9*9 window (see Figure 1). In the case of RATTAN and WOOL, it was a 25*25 window. This size is related to the size of the basic pattern of each texture.

Practically, we have verified that 5 - 10 iterations were sufficient to obtain good approximations of the original natural textures. Table 1 shows the evolution of the criterion at each iteration. C_0 is the initial value of the criterion. The initial synthesized texture is white noise having the same histogram as the corresponding natural texture, so the mean and the variance of this white noise are already equal to the desired values which makes the convergence more rapid. Figure 2 shows the synthesized textures approximating SEISMIC PICTURE after 1 to 8 iterations. Figure 2 is composed of two 512*512 pictures, each being divided into four 256*256 pictures corresponding to the various iterations.

Figures 4,5,6 and 7 are presented in the format shown in Figure 3. They show the results of the parallel synthesis of SEISMIC PICTURE, SAND, RATTAN and WOOL, respectively, after 8 iterations and their comparison with the original natural textures from which the feature vectors were computed. The reader can verify that the synthesized textures are very similar visually to the original ones.

This method gives us a way to synthesize artificial textures in a parallel manner from a compressed set of data with a good visual similarity to natural textures. We think that such a technique could be applied effectively for the generation of synthetic images in flight simulators or for computer generated movie films if a parallel computer were available.

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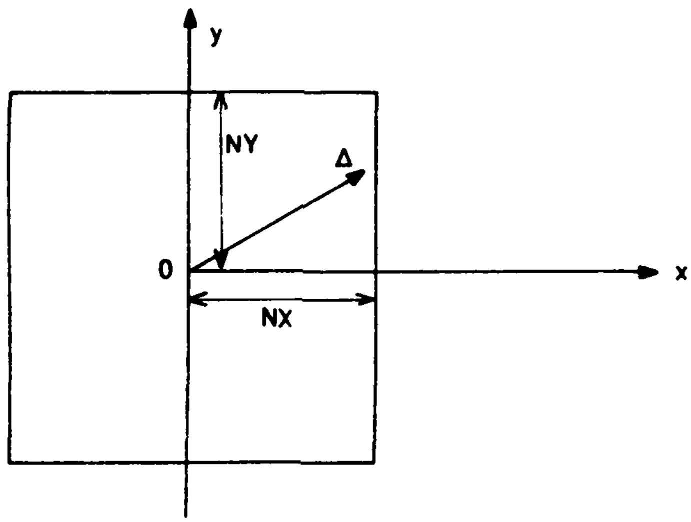

Figure 1 : A translation set $T\Delta$

Figure 2 : SEISMIC PICTURE synthesis, results after 1 to 8 iterations

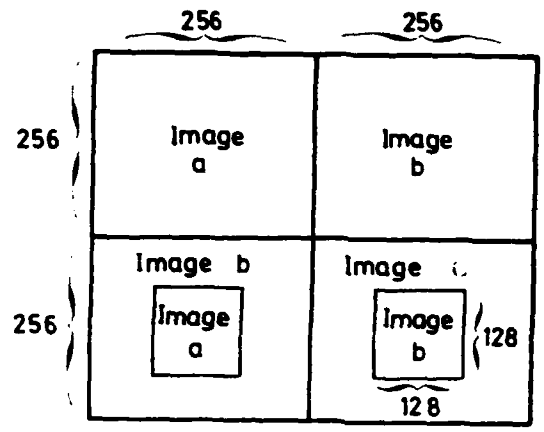

Figure 3 : Presentation format of Figures 4, 5, 6 and 7

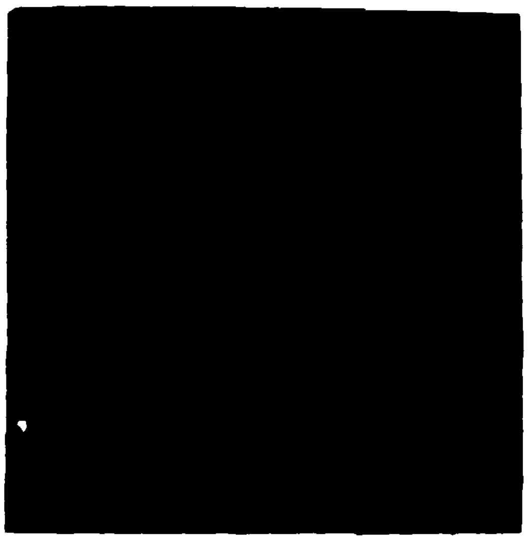

Figure 4 : SEISMIC PICTURE synthesis:

a) natural seismic picture b) generated texture

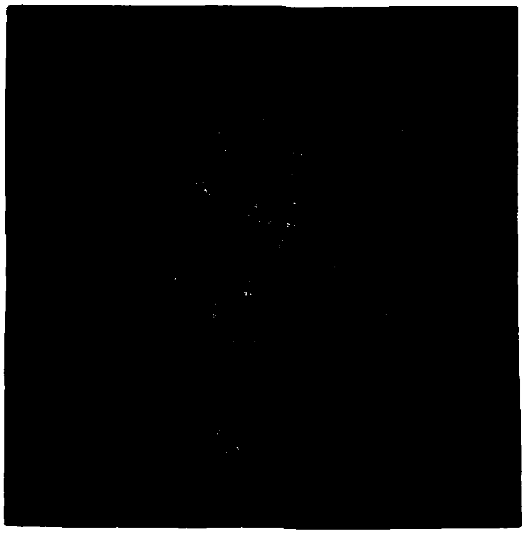

Figure 5 : SAND synthesis:

a) natural SAND b) generated texture

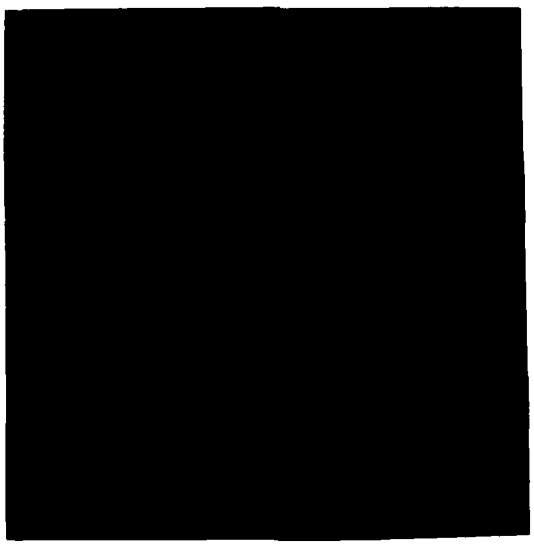

Figure 6 : RATTAN synthesis:

a) natural RATTAN b) generated texture

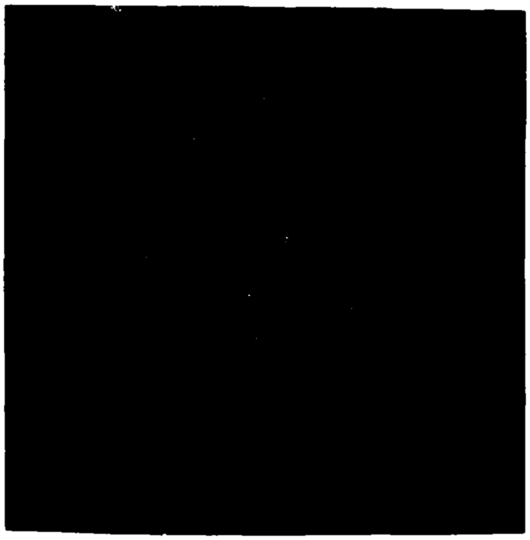

Figure 7 : WOOL synthesis:

a) natural WOOL b) generated texture

	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_8/C_0
SEISMIC PICTURE	0.142	0.116	0.098	0.080	0.061	0.046	0.034	0.023	0.014	9.9 %
SAND	0.080	0.066	0.052	0.038	0.027	0.019	0.012	0.007	0.003	3.8 %
RATTAN	0.024	0.022	0.019	0.016	0.012	0.009	0.007	0.005	0.004	1.7 %
WOOL	0.027	0.022	0.017	0.011	0.007	0.005	0.003	0.002	0.001	3.7 %

Table 1 : Evolution of the criterion C(X)

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